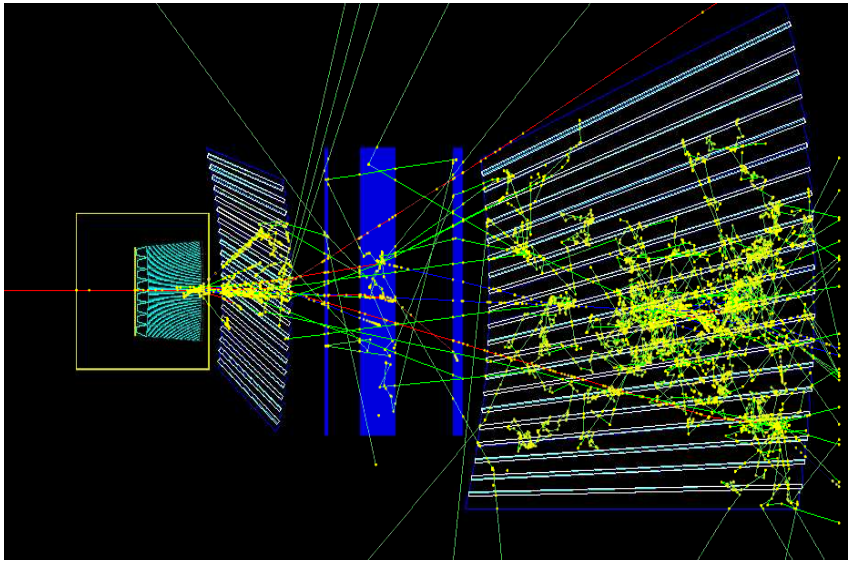
HCAL Calibrations

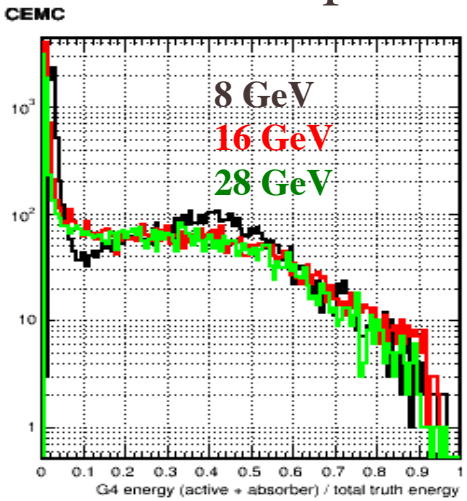
- Abhisek Sen

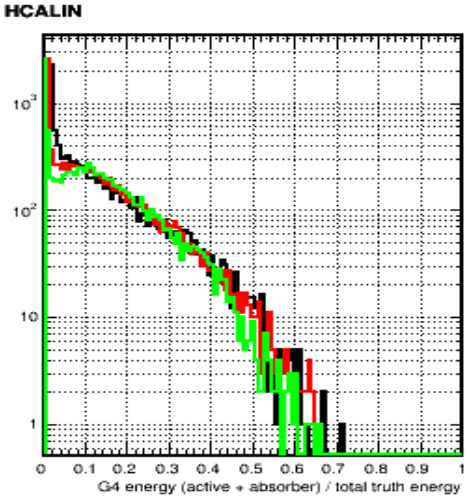
Simulations

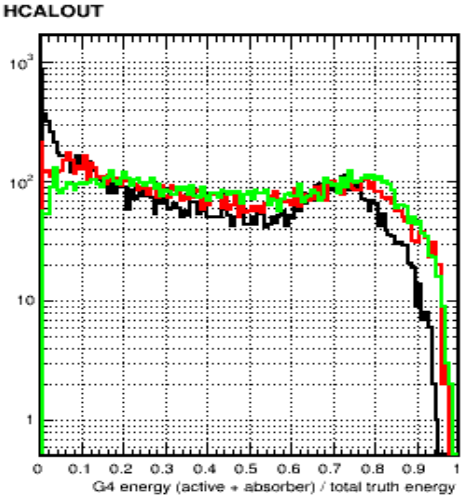


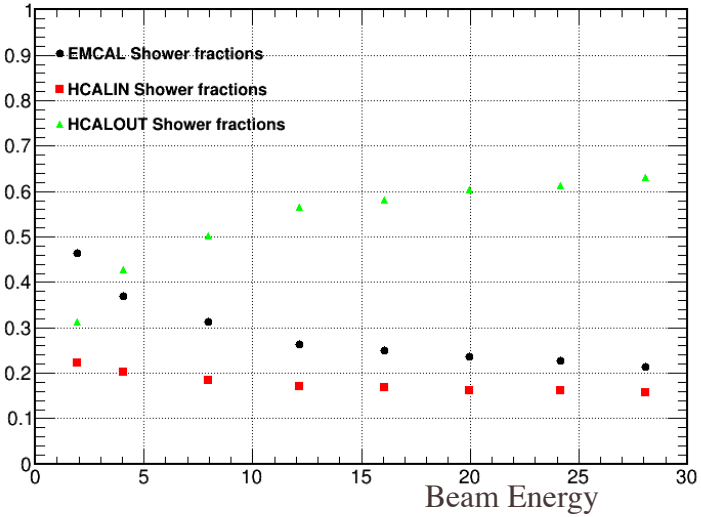
Pion showers : Truth

- Lets start with simulations for few basic facts.
- Simulated pions 0-32 GeV.









Hadronic energy resolution is mostly driven by the outer HCAL.

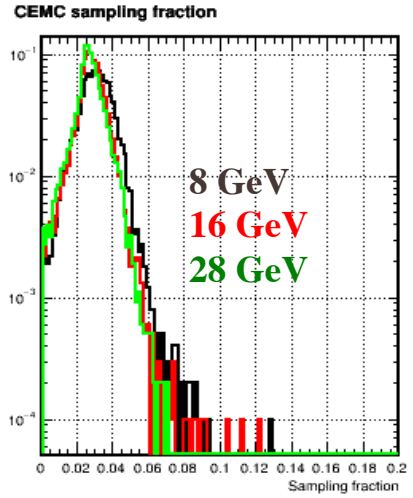
EMCAL ~ 1λ

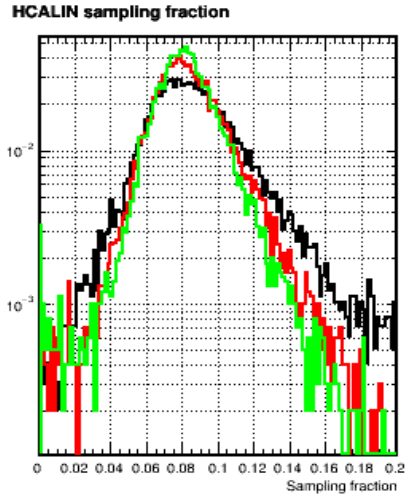
Inner HCAL ~ 1λ

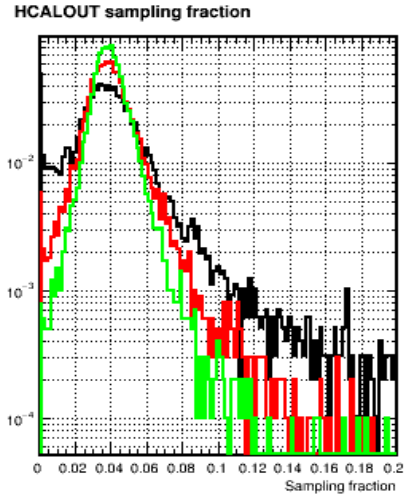
Outer HCAL ~ 3.5λ

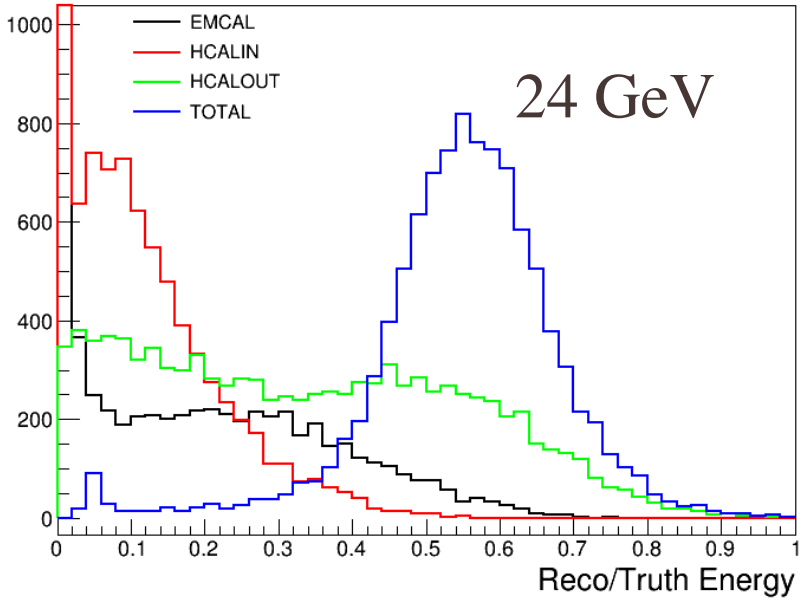
Pion Showers : Reco

- Sampling fractions for pions.



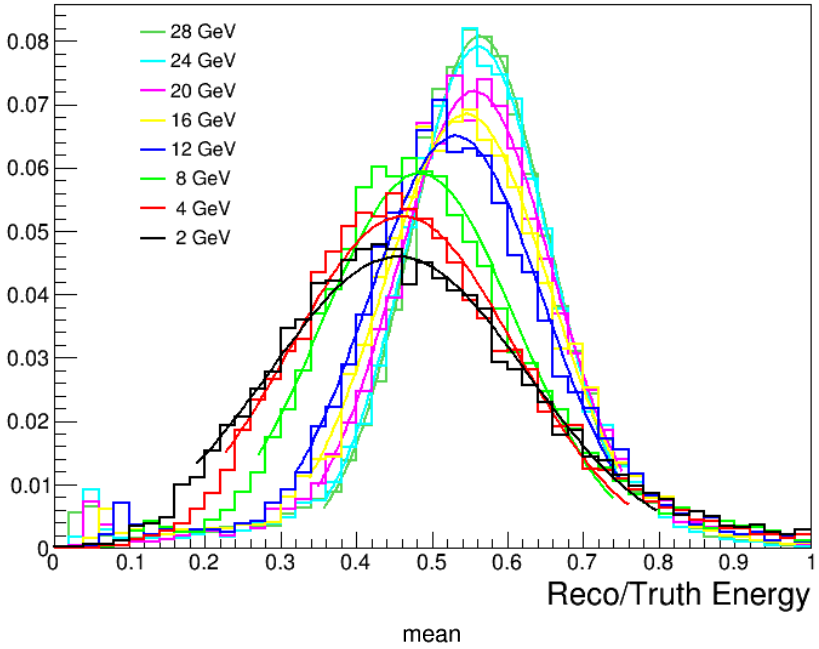




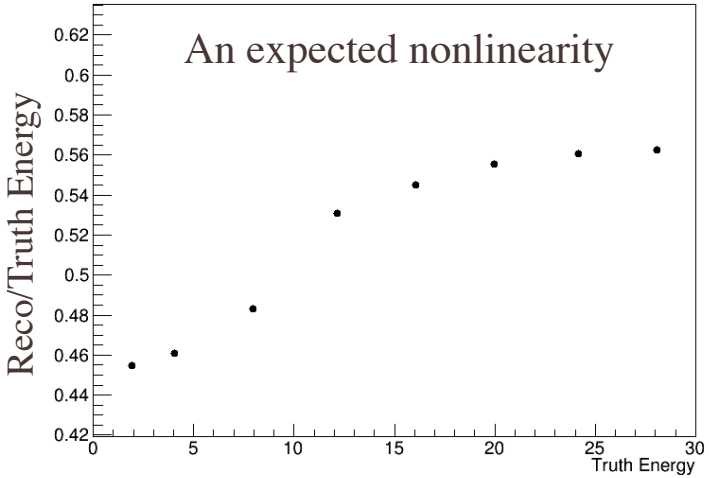


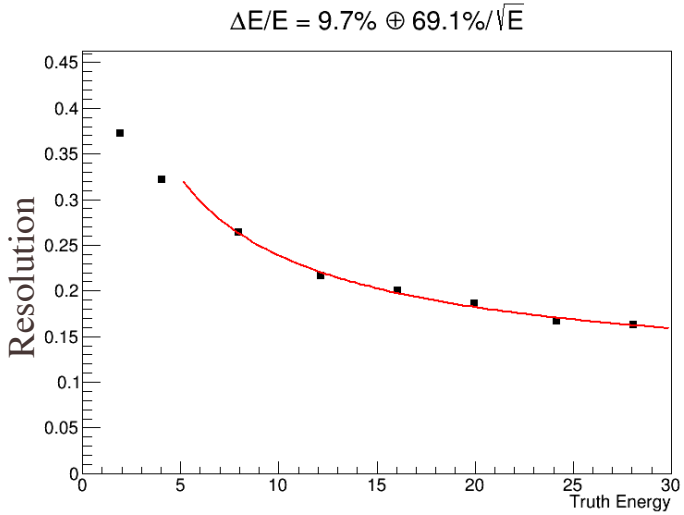
- Reconstructed energy from the simulated towers.
- Clear peak when you add all three calorimeters.
- Precise relative calibration is particularly important in segmented calorimeters like ours to reconstruct full energy.

Pion Showers: Reco2



- Reconstructed energy from simulated towers.
- Missing energy by leakage at the back and radial direction.
- Includes constant sampling fractions.
- No longitudinal center of gravity correction.



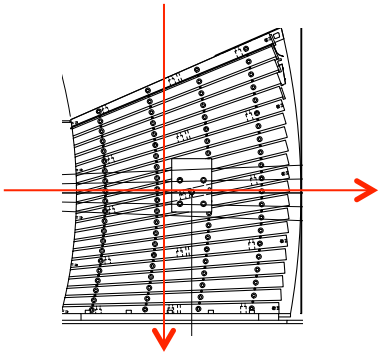


Data

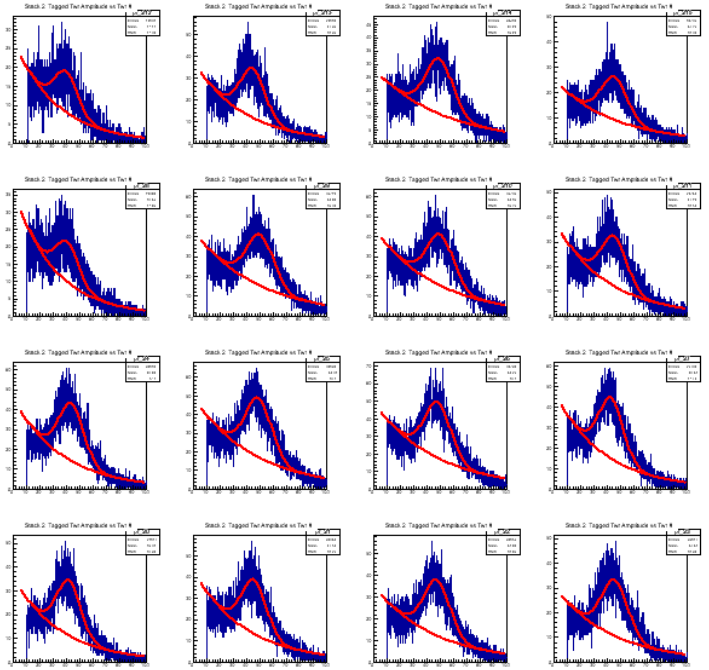
HCAL Tower-by-tower calibrations

- Collected cosmic data at highbay.
- Compared with cosmic simulations from Murad for a tower-by-tower calibration.
- We intended LEDs for another confirmation on the calibration but couldn't drive with all LEDs with same voltage and currents.

HCAL calibration done with cosmic μ's
Edep ~ 750 Mev/1 GeV (Inner/Outer).



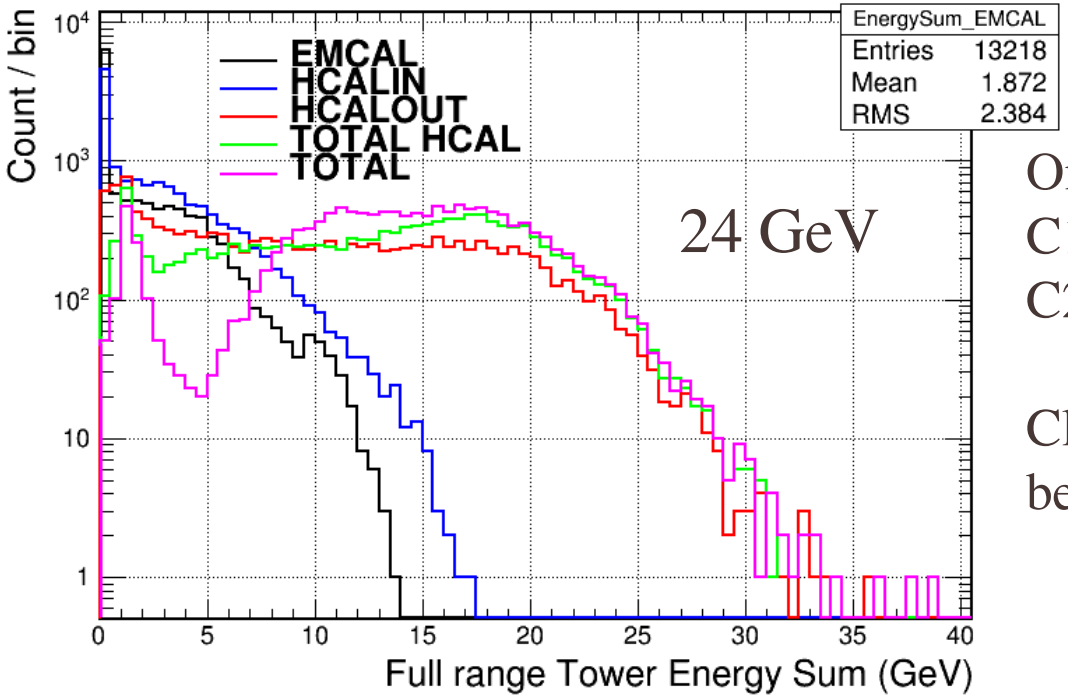
Does the geometry matter?



Example of Outer HCAL calibration with cosmic muons

All 3 segments of calorimeters

$$E_{reco} = \sum_{i}^{N_{towers}} S_i^{em} + \sum_{i}^{N_{towers}} S_i^{hin} + \sum_{i}^{N_{towers}} S_i^{hout}$$



Only "no Cherenkov signal" cut.
C1 inner energy <10
C2 outer energy <10

Clearly shows mis-calibration between HCAL and EMCAL.

Methodology

- Created a root minimizer to give best possible reconstructed energy.
- Tower-to-tower calibrations: HCAL:Cosmic, EMCAL:MIPs
- Overall scale:

$$E_{reco} = p_1 E_{EMCAL} + p_2 E_{HCALIN} + p_3 E_{HCALOUT}$$

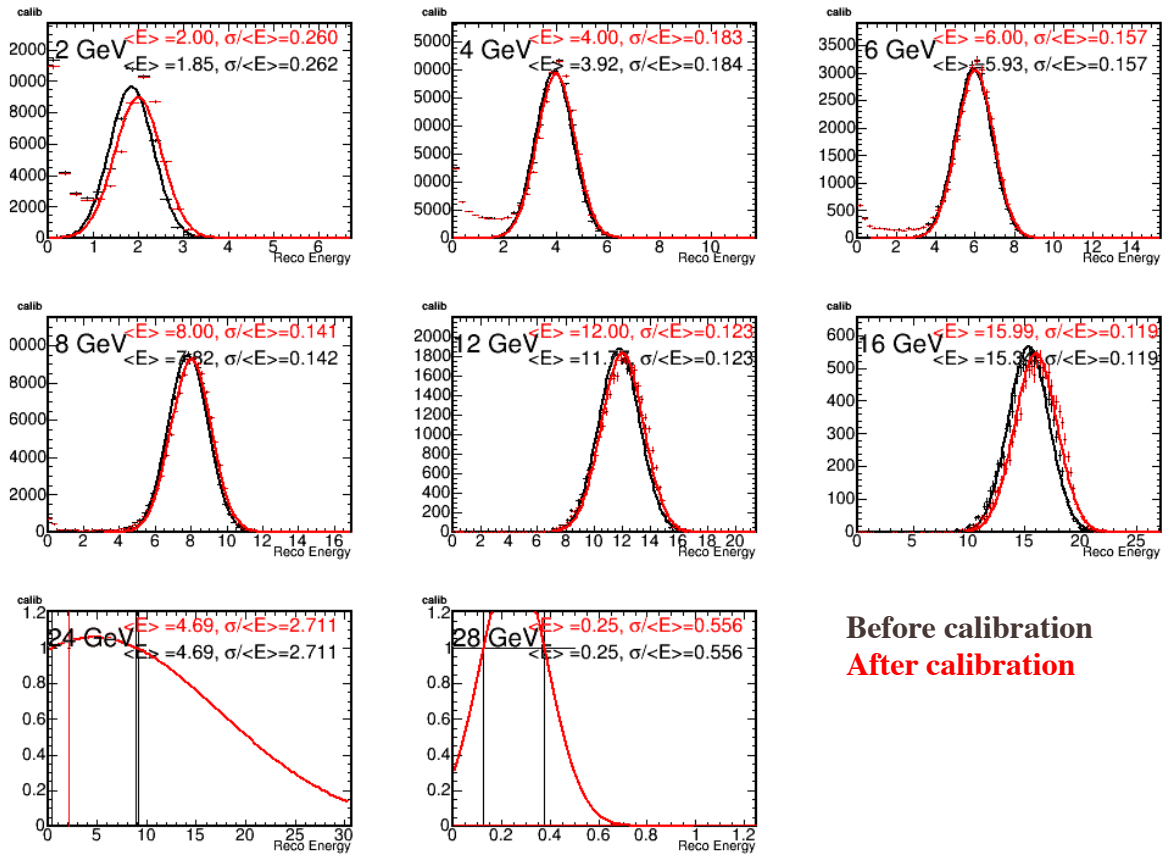
$$p \equiv Min \sum_{i=0}^{N_{events}} (E_{reco} - E_{truth})^2$$

- Used Minuit2:

```
ROOT::Math::Minimizer *min =
        ROOT::Math::Factory::CreateMinimizer("Minuit2", "Migrad");
```

- Three steps:
  - EMCAL: $E_{reco} = P_0 E_{EMCAL}$
  - HCAL: $E_{reco} = p_1 E_{HCALIN} + p_2 E_{HCALOUT}$
  - Total: $E_{reco} = p_3 E_{EMCAL} + p_4 (p_1 E_{HCALIN} + p_2 E_{HCALOUT})$

EMCAL calibrations with electrons



Before calibration
After calibration

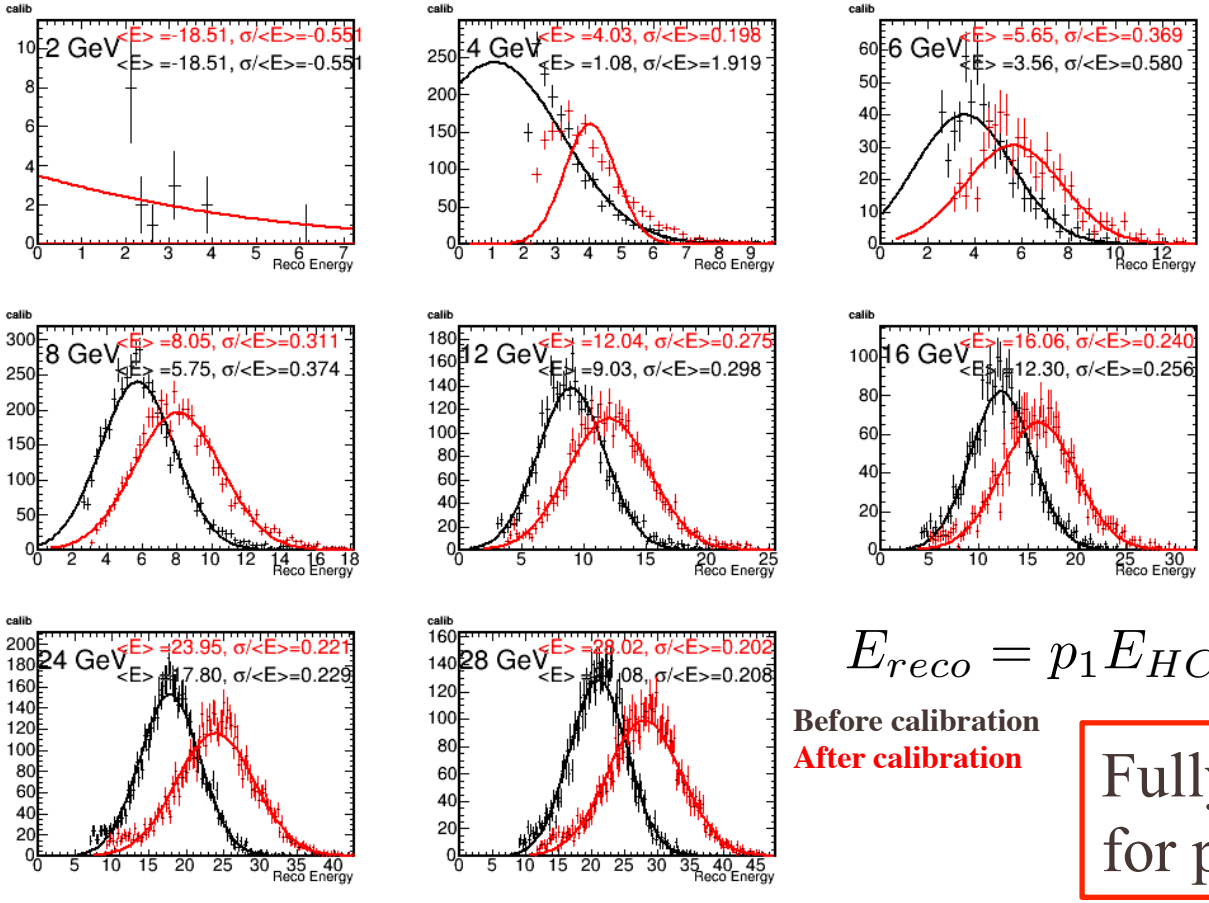
Energy	Calibration parameter
2	1.07951
4	1.0207
6	1.01162
8	1.02238
12	1.01977
16	1.04325

$$E_{reco} = P_0 E_{EMCAL}$$

- Using MIPs calibration for the EMCAL.
- Minor modification to overall scale.

Fully calibrated EMCAL for electrons

HCAL calibrations with pions



Using EMCAL MIP events

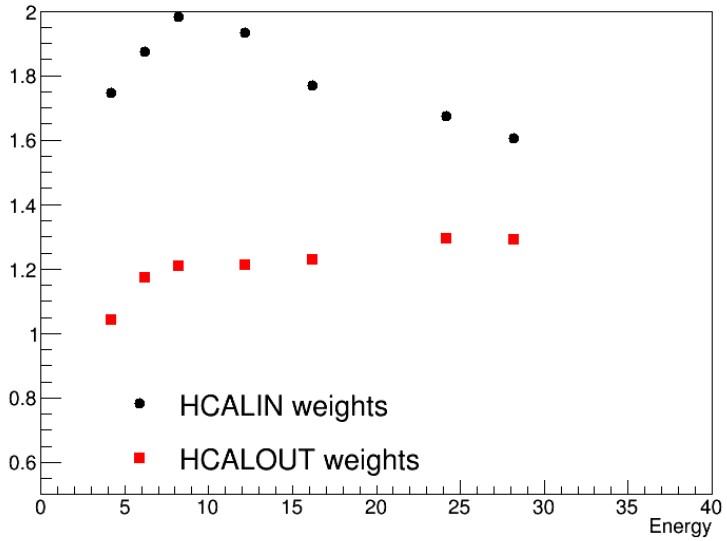
$$E_{reco} = p_1 E_{HCALIN} + p_2 E_{HCALOUT}$$

Before calibration
After calibration

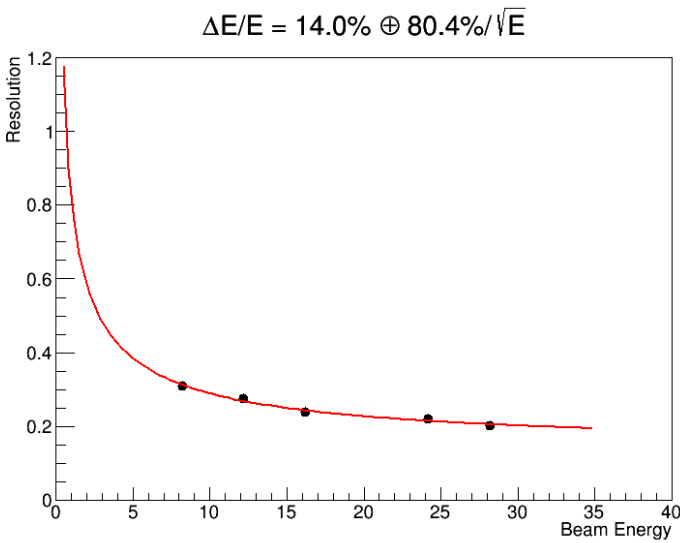
Fully calibrated HCAL for pions.

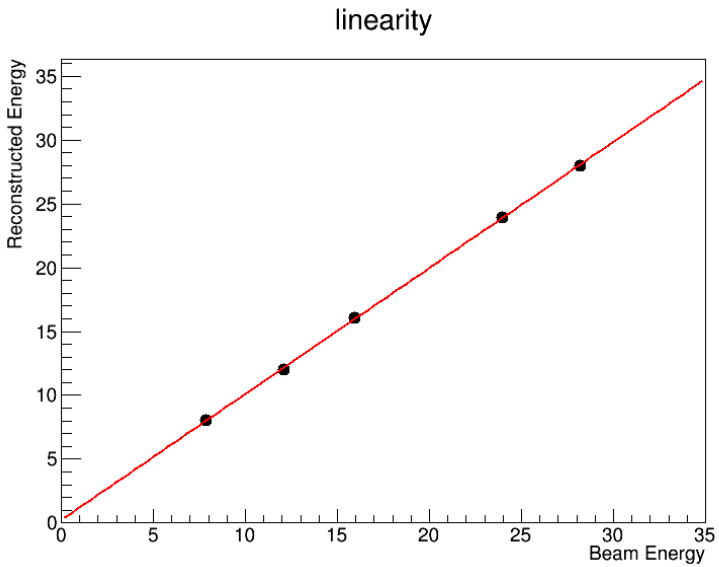
- Using cosmics tower-by-tower calibrations for the inner and outer HCAL.
- Major modifications to overall scale.

HCAL calibration parameters

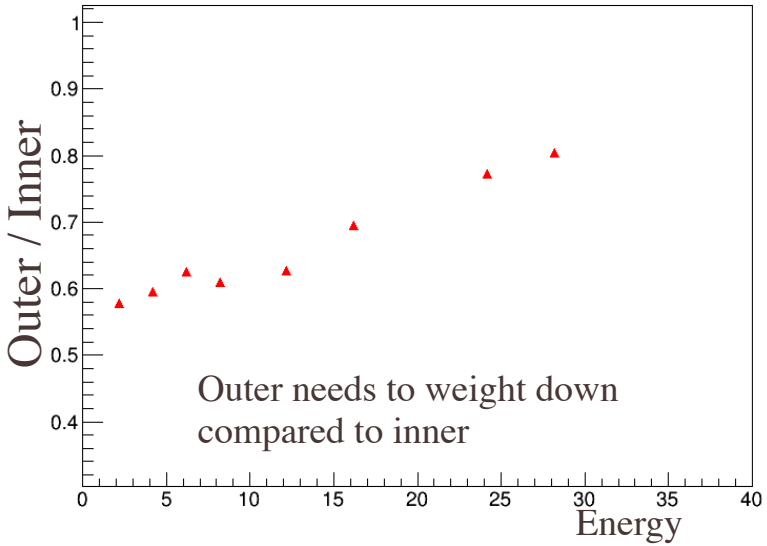


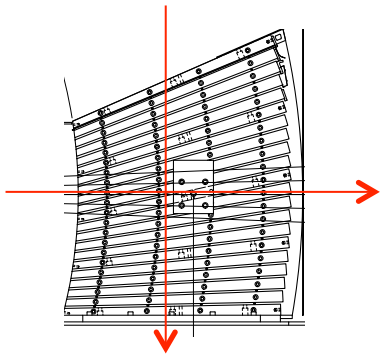
- Significant modification compared to cosmic calibration.
- Both segments (inner and outer) were underestimated.
- Inner HCAL has higher modifications than outer HCAL.





Why HCAL calibrations are so off?





Does the geometry matter?

Inner:
beam direction SF < cosmics SF
Outer:
beam direction SF > cosmics SF

How this could be?

Action item for this workshop

From Murad:

Inner HCal:

For cosmics SF=0.0811

For test beam fit SF = 0.0637

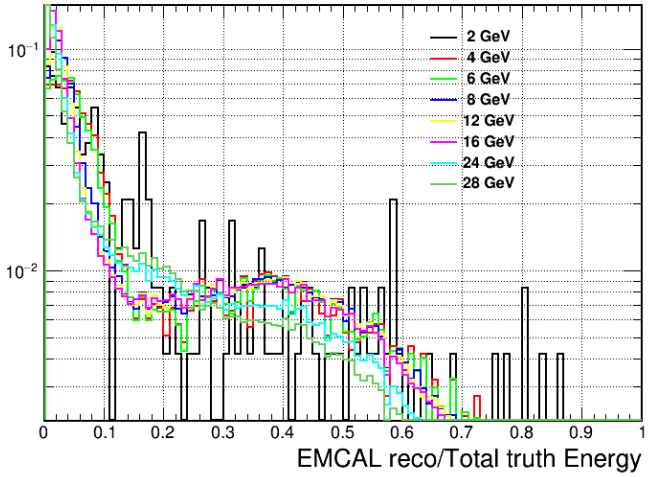
Outer HCal:

For cosmics SF=0.0287

For test beam fit SF = 0.0319

Path to full calibrations

- Most of the hadron showers deposit some energy in EMCAL before it reaches to HCAL.
- To this far we have:
  - EMCAL: calibrated for electrons
  - HCAL: calibrated for hadrons
- Remember EMCAL e/pi is not 1.

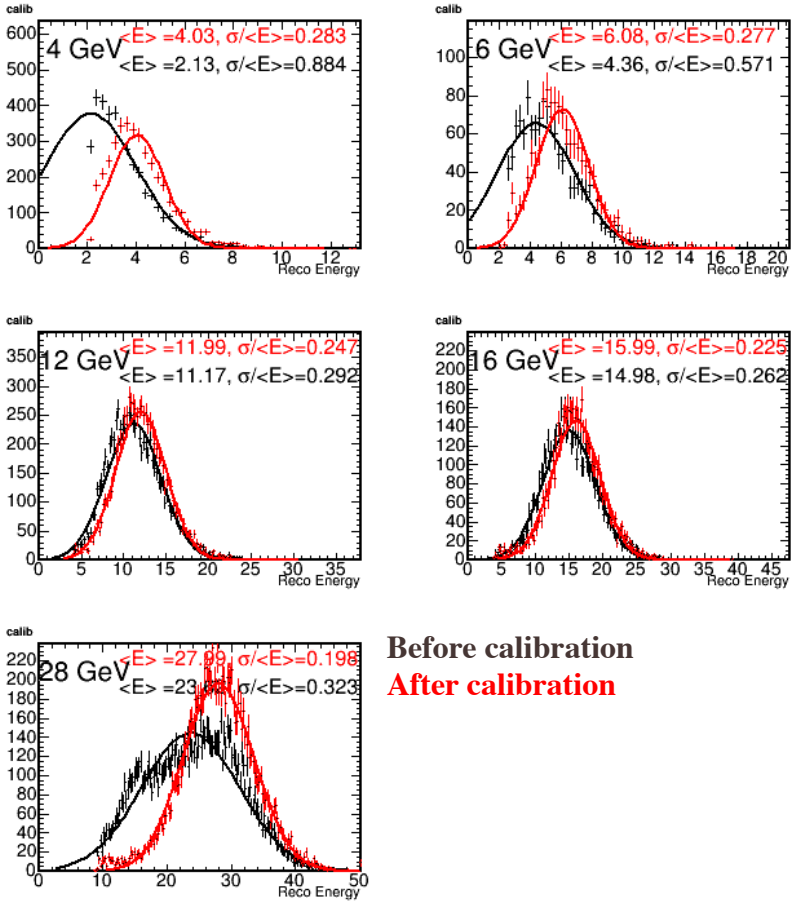


(unknown quantity)

- If shower starts in emcal, it will yield a lower energy because emcal e/pi > 1.

- Strategy:
  - Calibrate EMCAL for pions as well.

Full calibration with EMCAL+HCAL



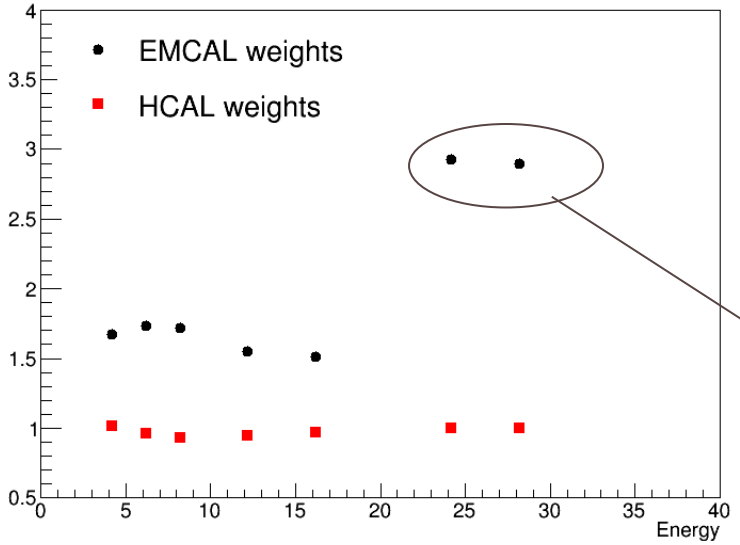
Using all hadron events.

Before calibration
After calibration

$$E_{reco} = p_3 E_{EMCAL} + p_4(p_1 E_{HCALIN} + p_2 E_{HCALOUT})$$

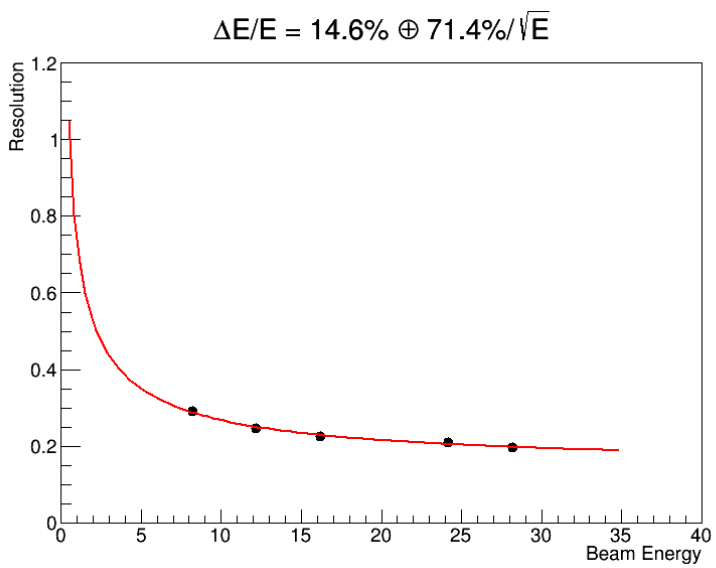
- Use electron calibrated EMCAL. P_3 expected to be emcal e/pi.
- Use hadron calibrated HCAL. P_4 expected to be ~1.

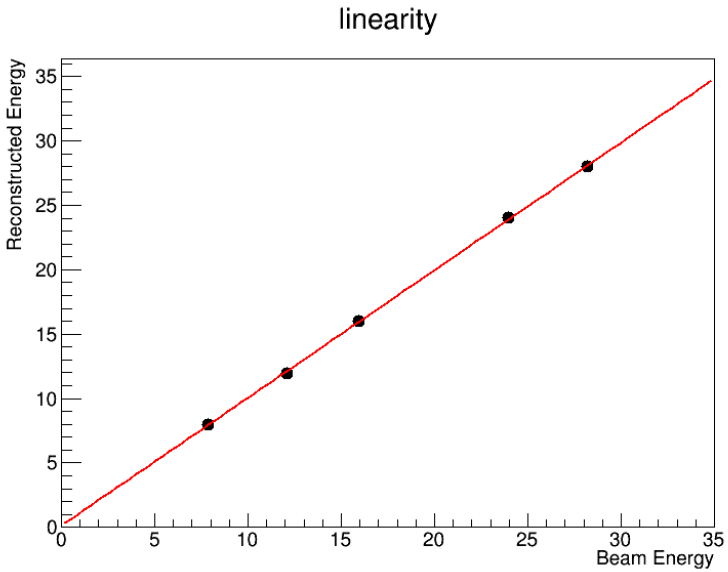
EMCAL, HCAL weights



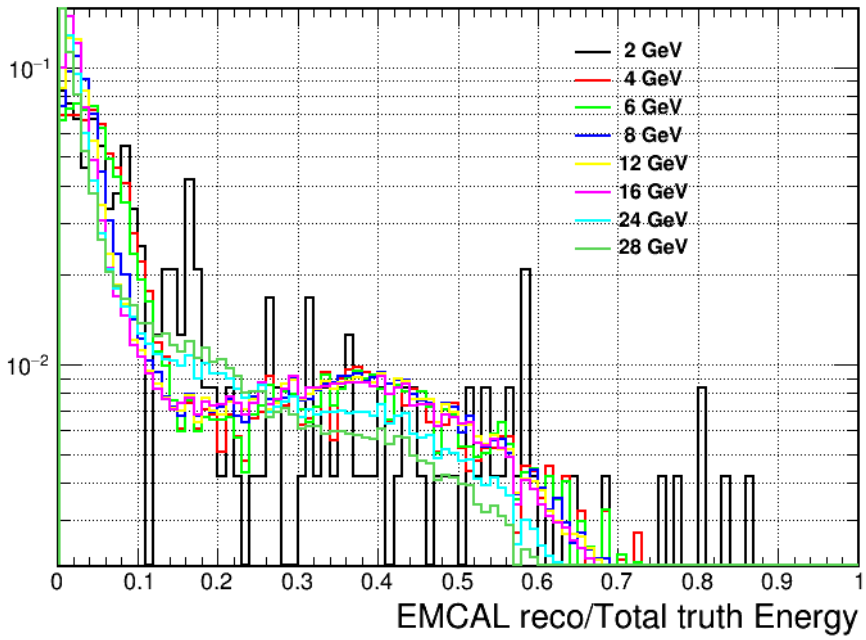
- HCAL weights are ~1 as expected.
- EMCAL weights represents EMCAL e/pi.

Running condition was changed for these two energies. EMCAL bias drop.





Calibration vs shower depth

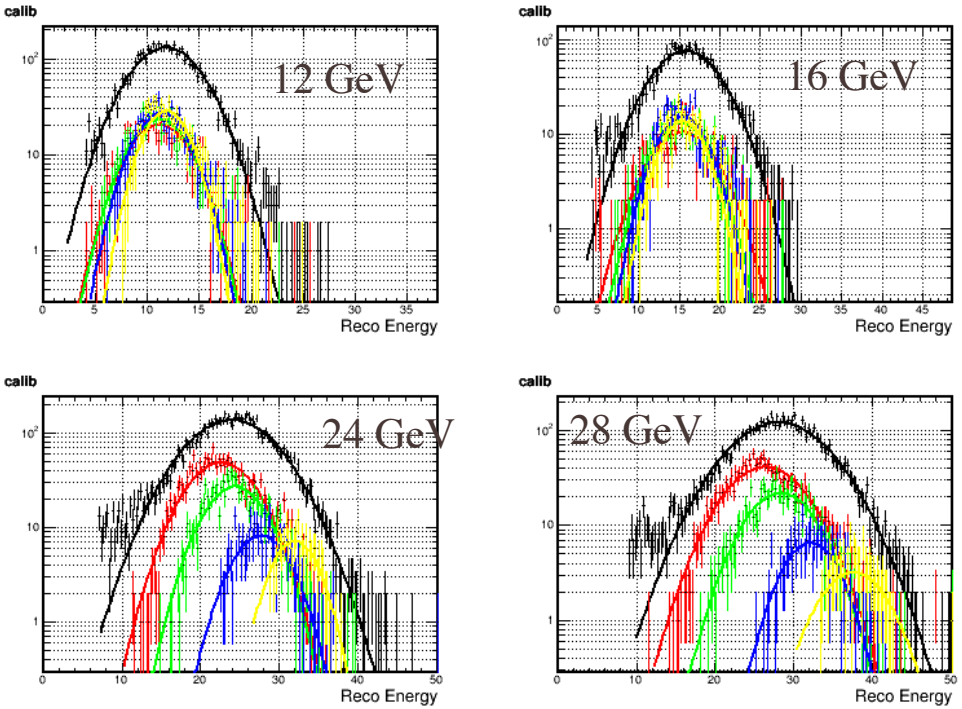


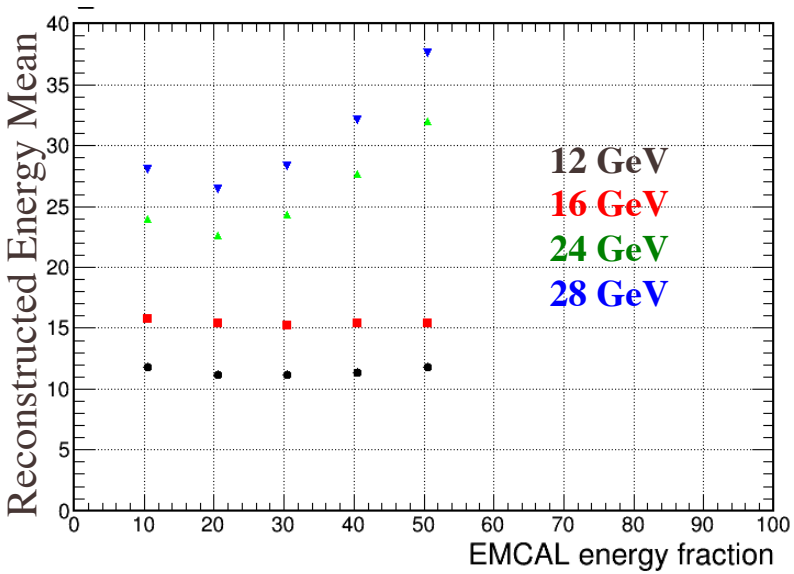
- Hadronic showers deposit 0-60% of energy.
- EMCAL ~ 1λ
- Do we need a position dependent shower response?

EMCAL e/pi is not 1.

A hadron shower deposit 10% of energy, another deposit 50% of energy in EMCAL. Will both have same calibration?

Shower depth vs Energy





- Sampled events depending on EMCAL energy in 10% bins.
- No much shower depth dependence for 12 and 16 GeV.
- Action item for this workfest.

Summary

- Hadronic energy resolution require precise balance between 3 calorimeter sections.
- Vertical cosmics alone does not provide full calibration for HCAL.
- EMCAL can be fully calibrated for electrons and hadrons.
- HCAL can be fully calibrated with EMCAL MIP events.
- Calibration changes with the shower depth needs more investigation.